REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
17-04-2013	Master of Military Studies Research Paper	September 2012 - April 2013

4. TITLE AND SUBTITLE
: Could Wind or Solar Energy Replace Diesel Generators for Aviation Ground Maintenance Operations?

5a. CONTRACT NUMBER
N/A

5b. GRANT NUMBER
N/A

5c. PROGRAM ELEMENT NUMBER
N/A

6. AUTHOR(S)
Rivera-Rivera, Jose O., SSA, FBI

5d. PROJECT NUMBER
N/A

5e. TASK NUMBER
N/A

5f. WORK UNIT NUMBER
N/A

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
USMC Command and Staff College
Marine Corps University
2076 South Street
Quantico, VA 22134-5068

8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
N/A

10. SPONSOR/MONITOR'S ACRONYM(S)
N/A

11. SPONSORING/MONITORING AGENCY REPORT NUMBER
N/A

12. DISTRIBUTION AVAILABILITY STATEMENT
Unlimited

13. SUPPLEMENTARY NOTES
N/A

14. ABSTRACT
The USMC is working to reduce their energy and logistic footprints, as a result, the USMC is looking fro green alternatives to reduce their dependency on fossil fuels. Wind and solar power, although two of the cleanest sources of energy, fall short of being the right alternatives to replace the use of diesel generators by the USMC to supply external power for their aviation ground maintenance operations. These two alternatives, when used independently, present several challenges related to their electricity generation capacity, thus rendering them ineffective and inefficient. In addition to these challenges, both systems have other issues when installed in the vicinity of airfields.

15. SUBJECT TERMS
Ground Support Equipment (GSE), Ground Power Unit (GPU), Photovoltaic (PV)

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
Unclass	Unclass	Unclass	UU		Marine Corps University / Command and Staff College
					19b. TELEPONE NUMBER *(Include area code)* (703) 784-3330 (Admin Office)

United States Marine Corps
Command and Staff College
Marine Corps University
2076 South Street
Marine Corps Combat Development Command
Quantico, Virginia 22134-5068

MASTER OF MILITARY STUDIES

TITLE: Could Wind or Solar Energy Replace Diesel for Aviation Ground Maintenance Operations?

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF MILITARY STUDIES

AUTHOR: SSA Jose O. Rivera-Rivera

AY 12-13

Mentor and Oral Defense Committee Member: Dr. Francis Marlo
Approved: Francis H. Marlo
Date: 17 April 2013

Oral Defense Committee Member: Dr. Richard DiNardo
Approved: [signature]
Date: 17 April 2013

Oral Defense Committee Member: CDR Russel Evans
Approved: [signature]
Date: 17 April 2013

Executive Summary

Title: Could Wind or Solar Energy Replace Diesel Generators for Aviation Ground Maintenance Operations?

Author: SSA Jose O. Rivera-Rivera, Federal Bureau of Investigation

Thesis: Wind and photo voltaic (PV) power systems are, arguably, two of the cleanest energy sources available today. Both methods have a great potential to generate power, given the right atmospheric conditions. Nevertheless, neither of these methods could function as an alternative to replace diesel generated electrical power for the USMC aviation ground maintenance operations.

Discussion: The USMC flies approximately 19,000 hours per year in Marine Corps Air Station (MCAS) Beaufort, SC. These hours are flown by F/A-18 fighter jets under the Marine Air Group 31. Fighter jets require a significant number of ground maintenance hours between sorties. During ground maintenance, all aircraft systems are energized by an auxiliary power unit (APU). The APU is a diesel generator. Units like Marine Aviation Logistics Squadron (MALS) 31 in Beaufort have numerous APUs to conduct ground maintenance. These APUs are in constant use, thus generating a large energy footprint.

As alternatives to decrease the energy footprint, wind and PV power systems were studied to assess their potential as possible sources of electrical power. Both of these systems depend on the sun to produce energy. Wind turbines depend on wind which results from the uneven heating of the earth surfaces. PV power systems depend on the sunlight which creates a chemical reaction within the sola PV panels to generate electricity. Therefore, both systems are limited by the atmospheric conditions. Without ideal conditions, windy and sunny days, both systems are rendered inoperative or inefficient. In addition to these limitations, both systems are costly and their installation brings a number of challenges.

For the wind turbines these challenges include: the obstruction created by the height of the turbines near airfields, the amount of land necessary for a 7 turbines wind farm, and possible interference with the air traffic control radars. The PV power system presents some challenges as well; it requires a big area for of 12,000 panels array, and could create reflectivity issues for the air traffic controllers. Furthermore, the installation of either system would require extensive construction work on-base and off-base for the transmission of power and its connectivity.

Conclusion: As a result, although wind and PV power are, possibly, the cleanest energy solutions, the costs involved and the challenges presented by either method outweigh their benefits. Additionally, the cost of generating the electrical power with the existing APUs is only a small fraction of the cost of either method.

DISCLAIMER

Table of Contents

List of Illustrations

Page

Preface

In the beginning of the academic year, I considered conducting research on a topic related to aviation from a pilot's perspective. After a conversation with my FACAD, I changed my mind and began looking for a topic related to the FBI. The ones that interested me were all classified or would have ended up being classified after combining all of the facts. As a result and after a conversation with Dr. Francis Marlo, I decided to go in a different direction.

Looking at the Lejeune Leadership Institute webpage I found a topic that grabbed my attention. It had to do with the USMC looking for alternatives to decrease the energy requirements within the aviation support operations of the Aviation Combat Element. Thinking that aviation support operations were related to aviation ground maintenance, a very familiar field for me, I decided to start exploring it. It did not take long to realize that aviation support operations in the USMC have nothing to do with aviation ground maintenance.

Before joining the FBI, I worked as an avionics technician on A-7Ds, F-16A/Bs, C-26s, and C-130Es. Once in the FBI and during my tenure in the San Juan Division, in addition to my duties of Special Agent/Pilot, I was the Aviation Maintenance Coordinator for the air branch. Between my military service and my time in the FBI, I have more than 20 years of experience in aviation operations and maintenance. As a result, I'm very familiar with aviation ground support equipment (GSE) and their operation. Anyone who has been around GSE for a long time, knows how annoying and contaminating GSE is.

Therefore, I was compelled to explore the possibility of using biofuels instead of diesel or jet fuel for the auxiliary power unit (APU), the most used GSE. To this end, I began researching ethanol as a possible biofuel. During the process I came to realize, that the production of ethanol in the U.S., although it is the highest in the world, fluctuates too much and there are too many unknowns as to modifying a diesel engine to operate on ethanol, unlike modifying gasoline engines to function on ethanol. Besides these unknowns, my knowledge of engines - diesel or gasoline - is very limited. Since engines are not my forte, I decided to refocus my research.

Since 2001 while I was in Germany, I saw a huge wind farm for the first time. I have been fascinated with them, ever since. Thus, I wanted to see the possibility of using them to replace the noisy APUs. Then, it was a matter of choosing a USMC installation to study the possibilities. In doing so, I wanted to focus on units flying fighters, as fighters have a high power demand, thus if the alternative worked for fighters, it could work for any kind of aircraft in the USMC inventory.

Once the unit was chosen and before the research began, I had a few assumptions on how the result of my research was going to look at. I was wrong. The result was very different to what I was envisioning. I guess that is the beauty of research.

During the research, I asked some people in USMC aviation maintenance, whom shall remain nameless, and I'm yet to hear back from them. However, one person in particular was very helpful; MAJ David Arenas, USMC Aviation Maintenance Officer, CG-1. I had the pleasure of sharing with MAJ Arenas during the elective period in the Masters of Insurgency class. MAJ Arenas was very helpful and I will always be thankful for his unconditional help. In addition, I'd like to express my acknowledgments to Dr. Francis Marlo for his help and patience, and Dr. Richard Dinardo for reviewing my work. Last but not least, I need to thank my wife, Marta Acevedo, for being there for me and for her continued support, and for proofreading my work, sorry to have put you through this. I could not have done this without you.

Introduction

The United States Marine Corps (USMC) is actively looking for alternatives to reduce dependency on oil and other fossil fuels. This effort is part of a U.S. government-wide initiative. This initiative is part of the current administration's policy. During his last State of the Union on February 12, 2013, President Barrack Obama emphasized on the need for the nation to continue moving in that direction. The USMC is already taking steps in an effort to reduce the energy footprint.

The USMC is employing a number of initiatives in, among other places, Marine Corps Air Station (MCAS) in Miramar, CA; MCAS Cherry Point, NC; and MCAS in Beaufort, SC. MCAS Miramar buys electricity from the Miramar Landfill project. This energy supplies almost 50% of Miramar's requirements and energizes more than 2,400 homes on base. In MCAS Beaufort the USMC is implementing a 400 kilowatts roof photovoltaic (PV) panels system. Also, irrigation water is reused and distributed through a double piping system to flush toilets and for cooling water (air conditioning chillers). Other changes include replacing incandescent lamps by fluorescent ones, and replacing shower heads and toilet flush valves to reduce water consumption. In addition to these changes in permanent bases in the U.S., the USMC Warfighting Laboratory (MCWL) is gathering information and knowledge on alternative energy technologies as part of the Experimental Forward Operating Base (ExFOB).[1]

The MCWL's initiative seeks to decrease the energy and logistic footprints by making the USMC more lightweight, flexible, and agile. However, the MCWL, at least on the September 10, 2012 edition of the Guide to Employing Renewable Energy and Energy Efficient Technologies, did not address any alternatives for large scale projects on permanent bases in the

Continental U.S. (CONUS). Additionally, the USMC Expeditionary Energy Strategy and Implementation Plan only address the subject as it relates to expeditionary operations. As a result, this study will focus on the viability of large scale alternatives for a permanent base in CONUS.

This study will focus on the aviation maintenance operations in MCAS Beaufort. It will evaluate the current use of the diesel ground power unit (GPU), and wind and PV power as energy sources to replace the GPU. It will determine the feasibility of using wind or PV power to generate the external electrical power for ground maintenance operations, replacing or supplementing the existing GPUs. It will also look into the cost of operating the GPUs, and the cost of the alternative sources. It should be noted, however, that although employing either of these methods (wind or solar) could result in a significant reduction of the energy footprint left by the aviation element in Beaufort, the conclusion won't be based solely on the reduction of the energy footprint.

As much as reducing the energy footprint is important, and wind and PV power are probably the best options to do so, the current state of the economy and an impending sequestration will be part of the equation when assessing the feasibility of using wind and PV power as alternatives. Any alternative under consideration has to be cost effective. The cost of generating electricity with either method is one of their shortcomings; the costs involved are very high. Cost, however, is not the only factor that makes the use of either method ineffective.

One of the problems with wind power is the space required for the installation of the turbines. In addition, turbines can't be located near airfields due to their height above the ground; thus the distance of the installation site from MCAS Beaufort brings the issue of power transmission. Lastly, wind turbines interfere with air traffic control radars, air traffic patterns, and airways. Just as wind power, PV power has several issues that, for the kind of application considered in this research, make its use ineffective and inefficient.

With the available PV power technology, the size of a solar farm to supply electrical power to the aviation element in MCAS Beaufort would be immense. As a result, the cost would increase significantly. Similarly, PV panels can't be installed in proximity to the airfield or the air traffic control tower. PV panels create reflectivity that could affect the air traffic controllers' vision. Thus, a PV power farm would have to be located distant from the airfield; this distance creates an issue with power transmission as well. Besides these issues, both wind and PV power have a few other things in common that makes their use ineffective and would render both systems inoperative.

Both systems require sunlight to operate. Wind is also a type of solar power; it depends on the uneven heating of the earth surfaces. Without heat or uneven temperatures, like those created by frontal systems and temperature differences between day and night, there would be no wind. This is why when the earth surface's temperatures equalize after sunset; the winds are typically low or calmed. Under such conditions the winds would be insufficient to propel the turbines and generate rotation. Likewise, PV systems depend on solar power to function and as such, do not produce energy when there are overcasts ceilings and during dark hours. Lastly, one of the biggest issues for the ineffectiveness of either method is the lack of technology to store their excess energy when not in demand. Due to the stated reasons, and although the wind conditions are superior in Beaufort, using wind or PV power system is not effective and will fall short of supplying the energy demand that is currently being fulfilled by the GPUs.[2]

MCAS Beaufort

MCAS Beaufort is located in the south east of South Carolina near the state line with Georgia. The location of MCAS Beaufort; when compared to the location of MCAS Miramar, CA and MCAS Cherry Point, NC; has better average yearly winds; thus if wind power is not an option for Beaufort; it certainly won't be for neither Miramar nor Cherry Point. As this study is focused in PV power as well, it is important to mention that the average solar radiation is very similar in the 3 locations, thus the same holds true for the use of solar power.

MCAS Beaufort is the home of Marine Aircraft Group (MAG) 31st. This MAG has 6 attack and fighter squadrons; among them, they operate approximately 60 F/A-18A/C/D. The F/A-18 has an estimated unit cost of $29,000,000. During 2011, MAG 31st flew approximately 18,900 hours and 11,532 sorties. In addition to the attack and fighter squadrons, Marine Aviation Logistics Squadron (MALS) 31st falls under MAG 31st. MALS 31st mission is the ground maintenance of MAG 31st's fleet.[3]

MALS 31st conducts the ground maintenance through the employment of ground support equipment (GSE). The most frequently used items in the GSE are the GPU, the hydraulic test stand, the air cooling unit (ACU), and the compressor. Emphasis will be placed on the GPU and the feasibility of replacing it by wind or PV power, as it is the most frequently used GSE item in military and civilian aviation. A short description of the GPU is provided below.[4]

A GPU is a diesel generator used in aviation to energize the aircraft while on the ground. Although all aircrafts have batteries that could energize some of the systems for a short period of time, connecting a GPU to the aircraft on the ground is necessary; aircraft systems have a very high demand for power and the battery is not capable of providing the needed power for longer than a few minutes. Also, not all systems are energized by the aircraft battery on the ground.

Winds and Solar Radiation in SC

According to the National Renewable Energy Laboratory (NREL) and as illustrated by Figure 1, the yearly wind speed at 80 meters (typical height of onshore large-scale wind turbines) is, predominantly, between 5 and 6 meters per second (MPS) or 11.2 to 13.4 MPH. Figure 2 is NREL's illustration for the average daily solar radiation for the entire U.S. As depicted on Figure 2, in SC the average is between 5 and 6 hours of radiation. According to NREL, even when average day is 12 hours long, full sun is obtained only between 5 and 6 hours a day.

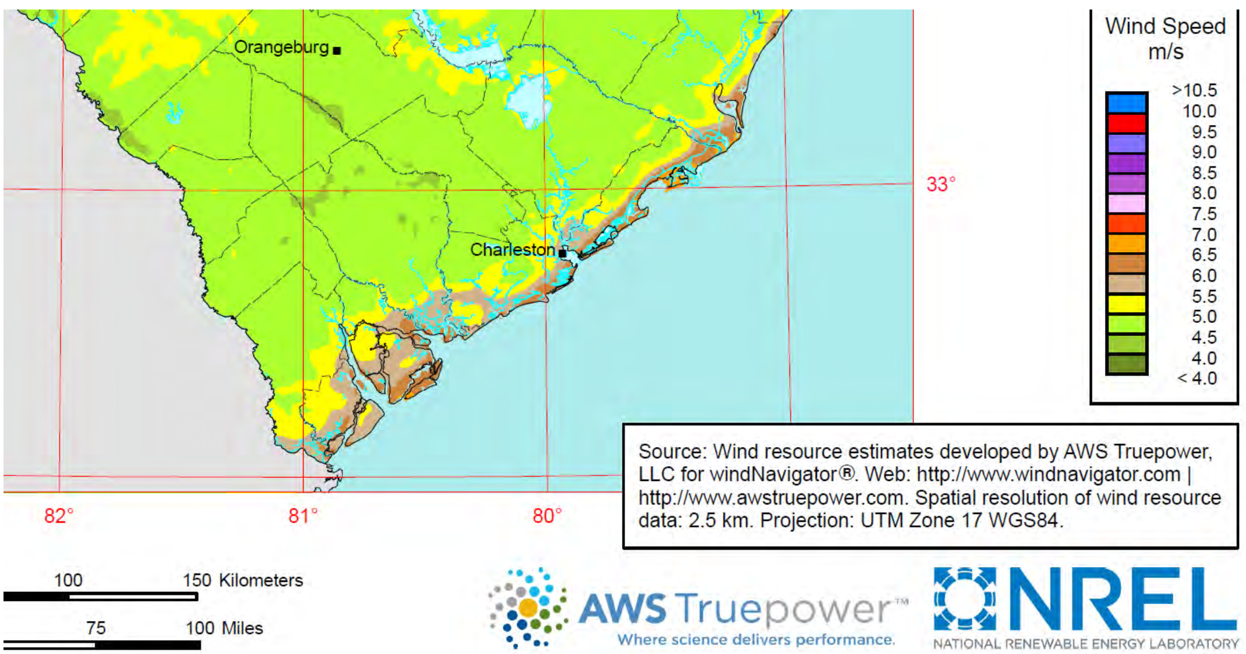

FIGURE 1

Electrical Theory

To have a better understanding of this study, one has to be familiar with a few basic concepts of the electrical theory. These concepts are voltage, electric current, power, and frequency. Voltage is pressure differential and its unit of measure is the volt (V). Electric current is the free flow of electrons through a conductor; its unit of measure is the ampere (AMP). There are two types of current, direct (DC) and alternating current (AC). DC is the kind of current stored in batteries and is very common in the automobile and general aviation industry. AC is the current used commercially, domestically, and by the military and commercial aviation. However, in addition to AC, military and commercial aircrafts use DC as well. AC can be converted to DC with a rectifier and AC can be converted to DC with an inverter.[5]

Power is the product of voltage and current; its unit of measure is the watt (W). Power is determined by multiplying the voltage by the current, thus the common formula is **P=IE**, where **P** represents power or watts, **I** represents current or amperes, and **E** represents voltage. This formula is important for the discussion as those three concepts will constantly be used when working with the outputs of GPUs, wind turbines, PV panels arrays, aircraft generators, auxiliary power units, and the power grid.[6]

The last of the basic concepts is frequency; its unit of measure is the hertz (HZ). HZ is cycles per second at which the electrical power is transmitted from the source (power grid, generators, etc.) through a conductor (power lines, cables) to the user. 60 HZ is the frequency used in the U.S., while 50 HZ is the standard in Europe. However, for commercial and military aviation the standard is 400 HZ.

The majority of industrial and domestic generators are designed to produce an output at 60 HZ. However, the generators used in commercial and military aviation are designed to produce an output at 400 HZ. The difference in frequencies lies on the distance of transmission of power to avoid voltage drops. However, this difference is not a limitation as conversion is possible from 60 HZ to 400 HZ.[7]

The wind turbines considered in this research have an output of 690 VAC @ 60 HZ. The PV panels considered in this research have an output 36 VDC @ 60HZ.

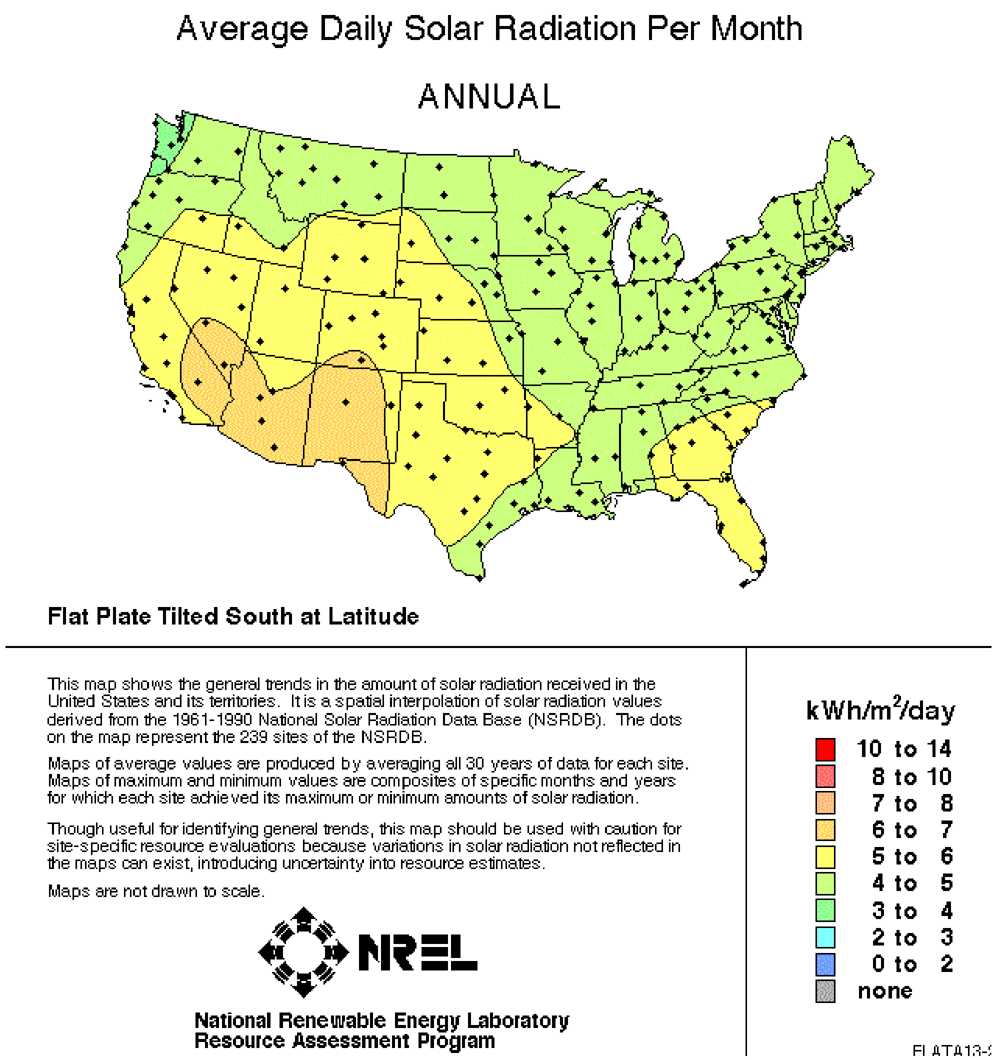

FIGURE 2

F/A-18 Specifications and Maintenance Requirements

The F/A-18 has an onboard Garrett AiResearch auxiliary power unit (APU), 200 horsepower (HP) and 150 kilowatts (KW). In addition each engine has an airframe mounted auxiliary drive (AMAD) that drives two separate 40 kilo volt amperes (KVA) generator (40 KVA is equivalent to 32 KW.[8]

The maintenance to flying hour ratio for the F/A-18 is approximately 6:1, which is typical in the military with fighter and attack jets. This ratio increases as aircrafts age. The 6 hours of maintenance are broken down into phased-inspections (every 200 hours of flight) and scheduled and preventive maintenance.[9]

Before and after every sortie, ground maintenance is performed. This maintenance includes tasks such as weapons loading, refueling, the repair of discrepancies, and troubleshooting to fix malfunctions. Typically, this maintenance requires between 1 to 2 hours of external electrical power.[10]

GSE Requirements

The A/M32A-108 is the most frequently used GPU by the USMC. The A/M32A-108 is a self-contained GPU powered by a 215 horse power (HP) diesel engine and capable of producing 115 VAC/28VDC at 400HZ. The power output is 72 KW. The voltage, frequency and power are compatible and enough to energize the aircraft during ground maintenance operations requiring external power. The cost of generating this output will be evaluated.[11]

Wind and PV Power:

Under the appropriate wind speed conditions, wind turbines are capable of generating a significant amount of electricity. Commonly, large wind turbines require a minimum ("cut in") wind speed of 3.5 MPS (approximately 8 MPH). As illustrated by Figure 3, between the cut in and the nominal wind speed (at which the highest output is generated) the power varies. The nominal wind speed for the type of turbine being considered is between 11 and 16 MPS (25 MPH to 36 MPH).

As illustrated on Figure 1, the yearly average winds in Beaufort are between 5.5 and 6 MPS. For this example, a 2.3 MW wind turbine will be considered. This size of turbine is one of the most common one in the industry for large-scale power generation. At nominal speed, this turbine could generate 2.3 KW. With the wind averaging between 5.5 and 6 MPS, based Figure 3, this turbine generates approximately 500 KW, the equivalent to 7 GPUs at full capacity. 500 KW is approximately 22% of the turbine generation capacity. According to NREL, for a turbine to be cost effective the ideal is 30% or above of the power generation capacity. In the interest of comparison, the same calculation should be made with PV panels.

To generate 500 KW with a PV system using a 300W panels, one of the panels with the highest output available, an array of approximately 1,667 panels is required. However, the highest output of PV panels is obtained around noon, during sunny days, and with the panels aimed directly at the sun, thus to generate the full 500 KW, the sun radiation has to be at full.

Predicting what the output will be is difficult with both of these methods as there is no control over the meteorological conditions. The calculations for the next section will be made assuming the sun is in full radiation and the wind is blowing at or above 5.5 MPS.

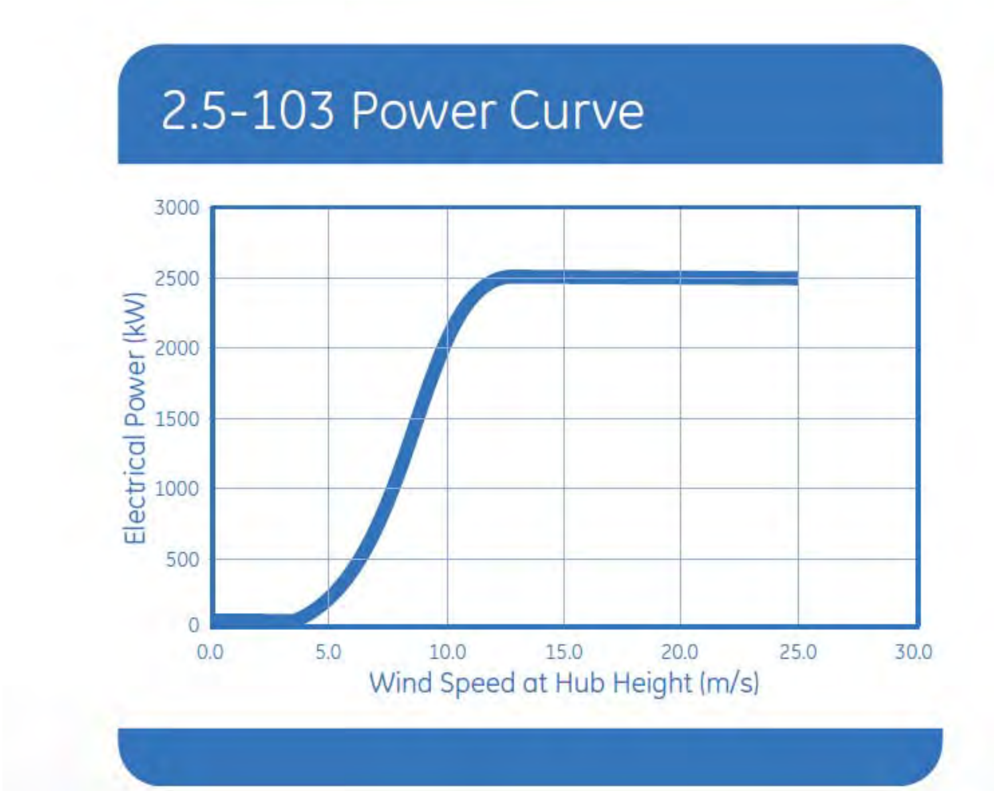

FIGURE 3 (Typical 2.3 MW Wind Turbine Power Curve)

<u>Supplying the Power Demand with Wind or PV Power</u>

The information on the command chronologies for MAG 31st does not reveal how the missions and the maintenance are broken down during the year. Additionally, they do not report how many missions are flown daily or how much maintenance activity takes place daily. As a result, for this example, the total sorties will be divided by 365 days. Using the 2011 command chronologies figures; if MAG 31st flies approximately 11,532 sorties during a year, it translates into 32 sorties per day, thus MALS 31st would require approximately 48 hours (1.5 hour per sortie) of external electrical power or approximately 3.5 MW per hour (MWH). To supply a demand of 3.5 MWH with turbines generating 500 KW per hour (KWH), a cluster of 7 turbines is needed. Supplying the same demand with PV power and using 300 W panels would require a solar farm of approximately 11,667 panels.

One must keep in mind that is unlikely these 32 sorties are launched simultaneously, and chances are the sorties are flown in separate missions or flights during the day, thus decreasing the power demand. On the other hand, even if the sorties are not flown simultaneously, if MAG 31st flies less than 365 days (which is very likely considering stand down days for weather, safety, etc.) the demand for power could increase. In addition to explore the requirements for supplying the power demand with both methods, is important to consider the costs involved with the GPUs and the two alternatives under consideration to determine the viability and benefits of using either of the renewable energy methods as an alternative to the existing GPUs.

Cost of Operating the Diesel GPUs

In South Carolina the cost of diesel is approximately $4.20 per gallon. The estimated fuel consumption for a diesel generator with a 215 HP diesel engine at full load is approximately 15.5 gallons per hour. 17,298 hours of ground maintenance with external electrical power would burn approximately 268,119 gallons of diesel during a year. The cost of the diesel would be approximately $1,126,099. Even when the costs of maintaining the GPUs and the fuel storage are unavailable, one could argue that the total cost would be significantly lower than the cost of generating the power with wind or sun.[12]

Cost of Wind Turbines, PV Panels, and Other Costs

According to Windustry, a non-profit organization registered in the U.S. to promote renewable energy solutions, the cost of wind turbines in 2012 ranges between $1,300,000 and $2,200,000 per MW, thus a 2.3 MW turbine could cost approximately between $3,000,000 and

$5,000,000 each. A cluster of 7 turbines could cost between $21,000,000 and $35,000,000. These figures represent the cost for the installation of the turbines; the cost of the land is not contemplated.[13]

Approximating the price of PV panels and the cost of a solar farm is somewhat more challenging than estimating the cost of wind turbines. Based on the prices of a distributor from California (the leader on solar power initiatives in the U.S.), 300W PV panels run for $251 in bulk. Consequently, a solar farm of 11,667 panels is approximately $3,000,000. Unlike the figures for the wind turbines, these figures do not include the installation on site. To have an idea as to the approximate cost, three solar farm projects in several areas in the CONUS and in Puerto Rico were considered.

In Cleveland, OH a project of almost one third the size will cost around $3,000,000. The cost a solar farm in Loiza, PR, about 10 times bigger than a farm for Beaufort, is $80,000,000. In North Carolina the cost of a project approximately 30 times bigger has a cost of $250,000,000. Analyzing the costs of these three projects, one could estimate that installing a 3.5 MW solar farm could be between $8,000,000 and $9,000,000. This cost does not contemplate the land for the solar farm. Additionally, neither the installation cost for the wind turbines nor the solar farm include the following factors: power transmission, to include step up and step down substations; and any construction associated to modifications necessary for connectivity in the flight line. [14]

Although the cost of power transmission and modifications for the connectivity in the flight line are unknown, undoubtedly, factoring them in would raise the total cost of either method exponentially. In addition to the above expenses, the size of the necessary lot and their costs come into play for both methods. A 2.3 MW turbine is approximately 80 meters high with the blades have a diameter close to 100 meters, thus the total height is around 130 meters above the surface. According to the NREL, the footprint of turbines of this size is ¼ acre (1012 m^2) and they are installed with a distance of 5 to 10 diameters apart. As such, 7 turbines could require from 25 to 50 acres of land. According to landwatch.com, the lowest price per acre in South Carolina ranges from $1,700 to $2,300 per acre. However, the prices near Beaufort range from $5,000/acre to 20 times that amount in certain areas. Based on the lowest figure for Beaufort, the land required for the installation could range from $125,000 to $250,000. However, there are many variables to be considered when choosing the site for the installation. Those variables will be addressed on the Limitations Section. The same is also true for the solar farm. [15]

A 300W PV panel is approximately 21 FT^2; this translates into an array occupying an area of approximately 7 acres. However, the size has to be bigger than 7 acres as this is the area that the PV panels would occupy with no service space between them. Based on the three solar farm examples considered before, the approximate size of the land for a 3.5 MW project could be between 13 to 18 acres. The cost of the site for the solar farm ranges from $65,000 to $90,000 using the above data. As with the wind farms, choosing the site for a solar farm involves a number of variables.

Challenges of Using Wind and PV Power

Besides all the costs involved with both of these methods, is important to explore all the challenges of using either methods as energy sources. The output of both, the wind turbines and the solar farm, are at 60 HZ. As mentioned in the GSE Requirements section, the necessary input to energize the aircraft for ground maintenance has to be at 400 HZ. To convert from 60

HZ to 400 HZ the use of frequency converter is necessary. The cost for the frequency converters is not available. However, converting the frequency is just one of the many challenges involved.

Turbines cannot be installed in the vicinity of airports. The rotating blades are known to disrupt the returns of primary and secondary surveillance radars used by air traffic controllers. These radars send coded signals to aircrafts and the transponders onboard the aircraft reply. The radar interprets the data received and controllers use the data on the radar display to maintain separation between aircrafts. The echo from the turning blades is interpreted by the radar as another aircraft (false return), so the turbines have the potential to generate many false tracks and targets. These false returns could jeopardize the safety of aircraft under radar surveillance and could clog the airspace. The latter could result of delays for arrivals and departures. The construction of wind farms could also compromise safety as airspace above wind farms are being designated as no-fly zones.[16]

In West Virginia a wind farm installed 7 miles from Kessel Regional Airport has created access problems and interference with the VHF Omni Range-Distance Measuring Equipment (VOR-DME). This navigation aid is used by pilots to navigate the airspace above the airport. It is also used for en-route navigation, and instrument approaches and departures when the weather does not allow to flight by visual reference and instrument meteorological conditions are in effect and pilots are required to fly solely by referencing their instruments. The Aircraft Owners and Pilots Association (AOPA) have complained to the Federal Aviation Administration (FAA) about the wind farm; as a result, the FAA has considered decommissioning the VOR-DME. The FAA is currently partnering with companies in the private sector, like Raytheon, to fix or remedy many of the interference issues; however, the height of the wind turbines still creates a challenge as they could obstruct air traffic patterns, and airways when installed in the vicinity of airfields.[17]

Any structure above two 200 feet above the surface has to be evaluated and approved by the FAA. These wind turbines are taller than 420 feet above the surface. Beaufort has two intersecting runways, thus approaches and departures are conducted to and from every quadrant. In addition, Beaufort approach charts call for a circling to land procedure on which the radius from the runway goes from 1.3 miles to 4.5 and the altitude is from 500 to 600 mean sea level (MSL). With a field elevation of 37 feet MSL and the turbines height of 420 feet above the surface, their height could reach over 457 feet MSL, just 43 feet below the lowest altitude for the circling to land procedure.   As a result, the wind turbines would have to be installed off base; a distance of over 4.5 miles, in this case nautical miles (5.3 statute miles), falls outside of the boundaries of the base.[18]

Installing the wind turbines off base creates an additional challenge and adds to the distance of power lines. Depending on the distance, there could be the need to connect the output of the turbines (690 VAC @ 60 HZ) to a step up substation to compensate for the voltage drop resulting from the transmission. In which case, in addition to the step up substation, a step down substation would be necessary to decrease the voltage to the desired level at the base. Increasing the distance creates the need for other components such as longer power lines and transmission towers, unless underground transmission is chosen. Underground transmission could bring a number of issues and increase the cost exponentially. Underground transmission will not be addressed. To mitigate these cost however, the turbines output could be connected to existing city transmission lines. This is known as parallel generation. [19]

Doing so, would eliminate some of the cost associated with the distance from the wind farm to the base. However, this option is not without some challenges and would also require the same type of modifications on the flight line for connectivity. Also, during times of low generation, the power would be drawn from the grid and thus would not be free of cost. Estimating the cost of electricity to be paid for city grid power would be very difficult. Using a PV power system comes with some challenges too. One of these is somewhat similar to those of wind farms.

There has been at least one known case on which a solar farm had some impact on aviation. At the Manchester-Boston Regional Airport a solar farm installed on a parking garage near the control tower has created reflectivity problems for the air traffic controllers. The controllers have complained about being blinded by the reflections during daylight hours. This project is less than 20% the size of the one being considered. The pilots, however, have not complained about being blinded by the reflections. This problem has forced the airport administration to cover the solar panels with tarps. Additionally, the panels have been rearranged in more than a few occasions. On the other hand, there are a number of airports in the U.S. where solar farms are in use. Two of them are Denver, CO and Indianapolis, IN. In both of these locations there have not been any complains either from air traffic controllers or pilots. However, the locations of these solar farms are farther away from the control tower than in Manchester-Boston. Another challenge with both methods is the selection of the installation site.[20]

Choosing a site to build a wind farm involves considering a number of factors and requires the approval from the FAA office of Obstruction Evaluation / Airport Airspace Analysis (OE/AAA). This is a lengthy process and could take over a year. The other factors to be considered are the proximity to neighborhoods, as the noise of the turbines and the turbulence generated could be disturbing to the neighbors. Turbines are also problematic for birds, so areas where endangered species have their habitats must be avoided. If using parallel generation, the wind farm should be located near city grid 3 phase power lines; however, the utility company must approve the installation.[21]

As noted above, solar farms present a number of challenges similar to those of wind farms when selecting the installation site. The site for a solar farm has to be free from obstructions and there should not be any structure that creates any shadows on the panels. Shadows over partial areas of the solar farm arrays create a bias problem and lowers the output significantly. The panels have to be directly facing the sun to produce the highest possible output. If the solar panels are fixed and not on auto track, they will generate the highest output for just a short portion of the 5 to 6 hours of sun in the area of Beaufort. However, using auto track could raise the cost significantly. In addition to the challenges, there are certain limitations resulting from lack of technology and Mother Nature. These limitations are harder, if not impossible to overcome.

Limitations and Drawbacks of Wind and PV Power Systems

Often times, the majority of aviation ground maintenance takes place very early in the morning, either prior to the first sorties or at the end of the day when all sorties have been flown. The possibilities are endless. Also, the USMC flies a great number of sorties during the night. Commonly, during all of these periods, winds are usually calm or not enough to generate sufficient power. Therefore, the output of each turbine drops under 500 KW. If the winds are below 3.5 MPS the turbines won’t generate any power. In addition to these scenarios, turbines are likely to be completely inoperative during the nights. PV power systems present similar limitations. [22]

PV power systems are completely dependent on sunlight and need the sun radiation to be at full to generate the maximum output. During days with overcast ceilings and nights, PV power systems are rendered inoperative and will not generate any electricity. As depicted in Figure 2, the area of SC gets a daily average of 5 to 6 hours of sun radiation. This average is not favorable as the highest demand for power is likely to occur outside of the periods when the sun is radiating at its maximum intensity. A remedy to this problem would be to add more panels to the array; however, this would only be effective if the higher demand for power happened during daylight hours the majority of the time. Hence, estimating what the right number of extra panels is difficult as the times for the highest energy demand varies. How this time varies depends on many factors, among them are the needs and priorities of the USMC, the weather conditions, and the seasons. The same is true for the wind turbines.

If the number of turbines was to be increased, the power generation would increase as well. However, the factors affecting the times for the highest demand of energy have the same effect on wind turbines. In addition to these limitations, a big drawback is the lack of storage technology.

The existing technology for storing large scale amounts of energy is not readily available. There have been studies on using excess power generated by turbines and store it as compressed air into caverns and salt domes and then use it by releasing it to spin turbines to generate electricity. This is known as compressed air energy storage. However, this technology is only available in two places in the world, McIntosh, AL and Huntorf, Germany. Research is being conducted on high capacity batteries, but this technology is not ready yet. All of these limitations show that even with ideal conditions, both methods fall short of fulfilling the high energy demand of the aviation ground maintenance operations.[23]

Conclusion

This research was conducted with the idea of studying the viability of using either wind power or PV power to replace or supplement the GPUs on generating the external electrical power for aviation ground maintenance operations in Beaufort. This location was selected based on its yearly average winds. The winds in Beaufort are superior to the winds in Miramar and Cherry Point. The average sun light hours, however, are very similar for the three locations. Therefore, the findings of this study could be employed to conclude that what does not work for Beaufort, would not work for Miramar or Cherry Point.

Although these two systems, wind and PV power, are possibly the cleanest with little or no energy footprint, they are not an option to supply the high energy demand. The winds in Beaufort are not enough to maximize the generation capacity use of the wind turbines. With the prevailing winds, the generation is below what is considered by the NREL as the minimum for a turbine to be efficient. NREL considers 30% of the generation capacity as the minimum, with the winds in Beaufort; the turbines would be generating only 22% percent of their capacity. Also, since the wind depends heavily of the uneven heating of the surfaces by the sun and are usually calm during the night, chances are that the turbines could only supply the energy demand, in the best possible scenario, for no more than 50% of the time. For days with no-wind conditions or with heavy winds, the external power would have to be supplied by the GPUs.

In Beaufort with an average of only 5 to 6 hours of sun, the PV panels would only generate the maximum output during a few hours of the day, thus more than 75% of the time the external power would have to be generated by the GPUs. Besides the issues with low winds and a low average of daily sunlight hours, one of the biggest shortcomings is the cost of either system.

The cost of using wind power as an alternative is no less than $35,000,000 and this figure does not contemplate the costs of power transmission and all the construction involved to modify the flight line for connectivity. The above figure does not contemplate the costs of frequency converters. If all of these costs are factored in the equation, the final figure could reach the vicinity of $40,000,000. This is nearly 140% the cost of an F/A-18 or a system that could not fulfilled even 50% of the energy demand. The cost of using PV power as an alternative is lower than the cost of wind power, but it is still too high after evaluating its possible energy generation.

The PV power system, as noted above, costs less than the wind power system. Nevertheless, its generation capacity is much lower than that of the wind turbines. The PV panels could only generate a maximum of 3.5 MW with the sun radiating at the highest intensity. The turbines could generate more as each turbine is capable of generating 2.3 MW with nominal winds. Nevertheless, it is unlikely to be the case as the winds in the Beaufort area are well below the nominal winds. Without adding any panels to the PV power system to increase its capacity, its cost without the transmission from the installation site to the flight line and the modifications and construction for connectivity is $9,000,000. If the other costs are factored in, the figure could reach approximately $12,000,000. This is close to 50% the cost of an F/A-18 for a system that most likely would only be capable of generating close to 25% of the energy demand.

After evaluating all of the costs involved, the challenges, and the limitations, one has to conclude that neither method is feasible or cost effective. Neither of these methods is efficient enough for this kind of application, where a high energy demand exist. Even using either of them to supplement half of the energy demand in an effort to decrease the use of the GPUs would not be justified. Finally with the current state of the economy and the sequestration, using either of these methods is out of question.

Bibliography

Kubala, Thomas S. *Electricity 1 Devices, Circuits, and Materials.* New York: Thomson Learning, 2001.

Gibilisco, Stan. *Teach Yourself Electricity and Electronics*. New York: McGraw Hill, 2011.

Morrison, Ralph. *Electricity, A Self-Teaching Guide*. New Jersey: John Wiley & Sons, 2003.

Ed by Spick, Mike. *The Great Book of Modern Warplanes.* London: Salamander Books Limited, 2000.

Gleim, Irving N. and Gleim, Garret W. *Gleim Federal Aviation Regulations/Aeronautical Information Manual*. Florida: Gleim Publications Inc., 2009

---

[1] Department of Defense, *DoDLive, Military to Turn Landfill into Energy* (Department of Defense, July 12. 2011) http://www.dodlive.mil/index.php/2011/07/military-to-turn-landfill-into-energy/, USMC,*Energy efficiency aboard MCAS Beaufort* (Beaufort, SC: USMC, October 25,2012)
http://www.beaufort.marines.mil/News/NewsView/tabid/14981/Article/129411/energy-efficiency-aboard-mcas-beaufort.aspx

[2] US Department of Interior Bureau of Land Management, *Wind Energy Development Programmatic EIS Information Center* (Washington, DC: Department of Interior: 2009) http://windeis.anl.gov/index.cfm

[3] 02/04/13 MAG 31 Command Chronology Jan-Jun 2011, GRC USMC Archives

[4] David Arenas (MAJ, USMC Aviation Maintenance Officer) personal interview on February, 2013, reviewed MAG 31st Command Chronologies Jan-Jun 2011, Over 20 years of personal experience in the military aircraft maintenance field and as a commercial pilot flying for the FBI

[5] Thomas S. Kubala, *Electricity 1 Devices, Circuits, and Materials* (New York: Thomson Learning, 2001) 5-8, Stan Gibilisco, *Teach Yourself Electricity and Electronics* (New York: McGraw Hill, 2011) 17-29

[6] Thomas S. Kubala, *Electricity 1 Devices, Circuits, and Materials* (New York: Thomson Learning, 2001) ix

[7] Ralph Morrison, *Electricity, A Self-Teaching Guide* (New Jersey: John Wiley & Sons, 2003) 186

[8] Ed by Mike Spick, *The Great Book of Modern Warplanes* (London: Salamander Books Limited 2000) 278-279, Diesel Service and Supply, Electrical Power Calculators, accessed on 21March 2013
http://www.dieselserviceandsupply.com/Power_Calculator.aspx#kwtokva

[9] David Arenas (MAJ, USMC Aviation Maintenance Officer) personal interview on February, 2013

[10] Over 20 years of personal experience in the military aircraft maintenance field and as a commercial pilot flying for the FBI and also functioning as the FBI San Juan Aviation Maintenance Coordinator

[11] Technical Data Sheet Aircraft Ground Power Unit Model No. B951 Navy Designation A/M32A-108 page 2, accessed on 03/20/2013, http://www.essexelectro.com/Manuals/b951.pdf

[12] Diesel Service and Supply, Approximate Diesel Fuel Consumption Chart, accessed on 04 February 2013 http://www.dieselserviceandsupply.com/Diesel_Fuel_Consumption.aspx ; South Carolina gas Prices , accessed on 20 March 2013, http://www.southcarolinagasprices.com/index.aspx?fuel=D

[13] Windustry, How much do wind turbines cost? Accessed on 28 January 2013, http://www.windustry.org/resources/how-much-do-wind-turbines-cost

[14] Windustry, How much do wind turbines cost? Accessed on 28 January 2013, http://www.windustry.org/resources/how-much-do-wind-turbines-cost ; CRT Caribbean Renewable Technologies, accessed on 12 February 2013, http://www.crtenergy.com/pag.cgi?pag=installations; Sun-Catching Solar Farm to power CMHA's new headquarters is Kinsman neighborhood, accessed on 20 March 2013, http://www.cleveland.com/metro/index.ssf/2013/01/sun-catching_solar_farm_to_pow.html; Sustainable Business, Biggest Solar Farm in the East Coming to North Carolina, accessed on 20 March 2013, http://www.sustainablebusiness.com/index.cfm/go/news.display/id/24580

[15] Land Watch, The #1 online resource for land and rural retreats, accessed on 20 March 2013, http://www.landwatch.com/South_Carolina_land_for_sale/Beaufort_County

[16] Technology Today, Air Traffic Control Interference Mitigation a Raytheon, accessed on 20 March 2013, http://www.raytheon.com/technology_today/2012_i2/airtraffic.html

[17] Aircraft Owners and Pilots Association, Airports and State Advocacy, Wind turbines cause safety, access concerns for airports, accessed on 20 March 2013, http://www.aopa.org/advocacy/articles/2012/120510wind-turbines-cause-safety-access-concerns-for-airport.html

[18] Air Nav, KNBC Beaufort Marine Corps Air Station (Merritt Field), FAA Information effective 07 March 2013, accessed on 20 March 2013, http://www.airnav.com/airport/KNBC; Irving N. Gleim, and Garret W. Gleim, *Gleim Federal Aviation Regulations/Aeronautical Information Manual* (Florida: Gleim Publications Inc., 2009) 569

[19] Duke Energy Carolinas LLC, Parallel Generation, accessed on 20 March 2013, http://www.duke-energy.com/pdfs/SCSchedulePG.pdf

[20] New Hampshire Union Leader, 30 August 2012, Airport controllers complain of solar panels' glare, accessed on 17 March 2013, http://www.unionleader.com/article/20120830/NEWS02/708309966

[21] Federal Aviation Administration, *Obstruction Evaluation/Airport Airspace Analysis (OE/AAA)* (Washington, DC: FAA, 2012), https://oeaaa.faa.gov/oeaaa/external/portal.jsp

[22] David Arenas (MAJ, USMC Aviation Maintenance Officer) personal interview on February, 2013; Over 20 years of personal experience in the military aircraft maintenance field and as a commercial pilot flying for the FBI

[23] Yale Environment 360, The Challenge for Green Energy: How to Store Excess Electricity, accessed on 20 March 2013, http://e360.yale.edu/feature/the_challenge_for_green_energy_how_to_store_excess_electricity/2170/; Power South Energy Cooperative, CAES, accessed on 20 March 2013, http://www.powersouth.com/mcintosh_power_plant/compressed_air_energy